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DISTRICT HEATING BUSINESS MODELS AND POLICY SOLUTIONS: FINANCING UTILIZATION OF LOW-GRADE INDUSTRIAL EXCESS HEAT IN THE PEOPLE'S REPUBLIC OF CHINA

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Abstract

The People's Republic of China (PRC) has taken bold actions since 2016 to utilize low-grade industrial excess heat to improve the energy efficiency of district heating systems. This study aims to draw policy insights into the PRC's field experience of overcoming barriers to energy efficiency financing. Firstly, we investigate split incentives, third-party access, and lack of heat resource mapping as key barriers to investing in district heating energy efficiency projects. Second, to enable energy efficiency financing, we analyze three business models: a utility-led model with third-party access, a heat production competition model, and an energy service company model. The business model choice in large part depends on the integration level of production, transmission, and distribution activities in a given district heating system. Third, the heat prices must signal new investments in district heating capacity adequacy. We suggest four options for excess heat pricing, including system cost, free cost, a quantity target for clean heating, and indexing against the next best alternative. Finally, we conclude with policy implications to scale up energy efficiency financing in district heating. Although the analysis is specific for the PRC, the policy and financing issues are global opportunities to improve energy efficiency in district energy systems.

Keywords: energy efficiency, district energy system, district heating, excess heat

JEL Classification: Q48, H32

Contents

1. INTRODUCTION

Energy efficiency is a key national strategy for sustainable development in the People's Republic of China (PRC). In the 13th five-year plan (2016–2020), the country aims to reduce energy intensity per unit of GDP by 15% in 2020 compared to 2015. If the PRC's GDP grows by 6.5% annually over 2016–2020, this target implies increasing energy savings by 16% compared to 12th five-year plan, equivalent to absolute energy savings of 23 EJ (780 Mtce).

As a primary measure of improving energy efficiency, the Chinese government plans to promote the utilization of low-grade excess heat in district heating systems, with a target of replacing more than 1.5 EJ (50 Mtce) of coal-based heat production associated with heating more than 2 billion m^2 of buildings by 2020. This plan also aims to pilot clean heating projects in 150 cities. At the G20 Energy Ministerial meeting held in 2016, the newly endorsed G20 Energy Efficiency Leading Programme (EELP) highlighted district energy systems as a key area of future collaboration. In 2017, the PRC's National Development and Reform Commission (NDRC) published the Clean Heating Plan of Northern Region (2017–2020) as a guideline to promote clean heating in the PRC.

The PRC has the largest district heating system in the world. The heating area increased from 5 billion m^2 to 14.7 billion m^2 between 2001 and 2018 due to improved living standards and population growth. The annual energy consumption for space heating reached 6.2 EJ (212 Mtce) in 2018, representing about 21% of the total energy consumption in the PRC's building sector (Tsinghua University 2020).

The energy intensity of the heating services in the PRC, expressed as the ratio of heating energy consumption and heated floor area, decreased by 37% from 0.67 GJ/m^2 in 2001 to 0.42 GJ/m^2 in 2018. The replacement of small heat-only boilers by centralized combined heat and power (CHP) sources and widespread adoption of energy efficiency measures in the building sector explain some of the improvement in the space heating energy intensity (International Energy Agency and Tsinghua University 2015).

Heating services in the PRC rely heavily on coal. More than 90% of the building floor area is heated by coal co-generation (combined heat and power) and/or coal boilers. The capacity of natural gas boilers has increased to 8% of the total heating floor area. However, the relatively high cost of natural gas compared to coal makes district heating less affordable without government subsidies.

More than ever, the challenges of controlling air pollution and capping coal consumption have prompted the PRC to develop clean alternatives to its coal-dominant district heating system. For this, the government is engaging in a series of actions to recover excess heat to enhance the energy efficiency of district heating systems.

The use of excess heat and pressure is a major country-wide energy-saving measure (State Council 2016). Financial support policies, in the form of investment subsidies and preferential tax treatments, were provided over the period of the 11th^{h} and 12th five-year plans (2006–2015). Most commercially viable heat recovery projects have already been implemented. Indeed, in the PRC, about 55% of excess heat potential—mainly high and medium grade excess heat—has already been recycled for energy generation or on-site industrial processes (International Energy Agency and Tsinghua University 2015). However, low-grade industrial excess heat, usually defined as flue gas below 200℃ or liquid below 100℃, is rarely recycled for energy use.

While it is well known that the PRC has the world's largest manufacturing sector, producing a huge amount of low-grade industrial excess heat, the literature on this remains limited. Fang et al. (2013) and Fang, Xia, and Jiang (2015) conclude that recovering low-grade industrial excess heat for low-temperature district heating can provide multiple benefits for factories, heat-supply, and the society in the PRC. Li et al. (2016) study technological options and provide a cost-benefit analysis for the collection and delivery of industrial excess heat in the northern PRC. Likewise, based on cases in Denmark, the Energy Technology Development and Demonstration Program (2014) investigates the efficiency benefits of district heating networks through increased utilization of renewable energy and low temperature resources. Meanwhile, various barriers exist to prevent effective consideration of low-grade industrial excess heat for district heating purposes. Söderholm and Wårell (2011) highlight third-party access as the key barrier to introducing clean heat sources into district heating. The Energy Sector Management Assistance Program (ESMAP 2008) suggests that the PRC may need to implement market-based pricing and consumption-based billing to commoditize the heat supply and thus incentivize efficiency improvement. Liu, Yao, and Wei (2019) quantify the gap in energy efficiency improvement attributed to the information asymmetry between the government and industries in the PRC. This study aims to fill the knowledge gap through a comprehensive analysis of financing models and pricing schemes applicable to the utilization of low-grade industrial excess heat in district heating systems.

The remainder of this chapter is organized as follows. Section 2 describes opportunities and challenges of scaling up the integration of low-grade industrial excess heat into the district heating system. Section 3 investigates three business models for financing district heating energy efficiency projects. Section 4 examines four options related to excess heat pricing. Section 5 concludes with a range of policy options to enable energy efficiency financing.

2. OPPORTUNITIES AND CHALLENGES IN THE PRC'S DISTRICT HEATING MARKET

2.1 The PRC's Low-grade Excess Heat Potential

Tsinghua University (2018) investigates the technical potential for recovering and using low-grade excess heat from major industries in the northern PRC. The analysis concludes that there is a huge untapped potential of 3 EJ (100 Mtce) for the resources of industrial excess heat which can be used in district-heating networks. This amounts to roughly half of the current energy demand for district heating in the northern PRC (Tsinghua University 2018). In many cities, such as Shijiazhuang, Tangshan, Handan, Qinhuangdao, and Chengde, the quantity of excess heat can meet a significant part of heat demand. Tangshan has seen the amount of excess heat even surpass its heat demand. It is noted that in all these cities, a major part of the excess heat is characterized by a temperature lower than 50°C.

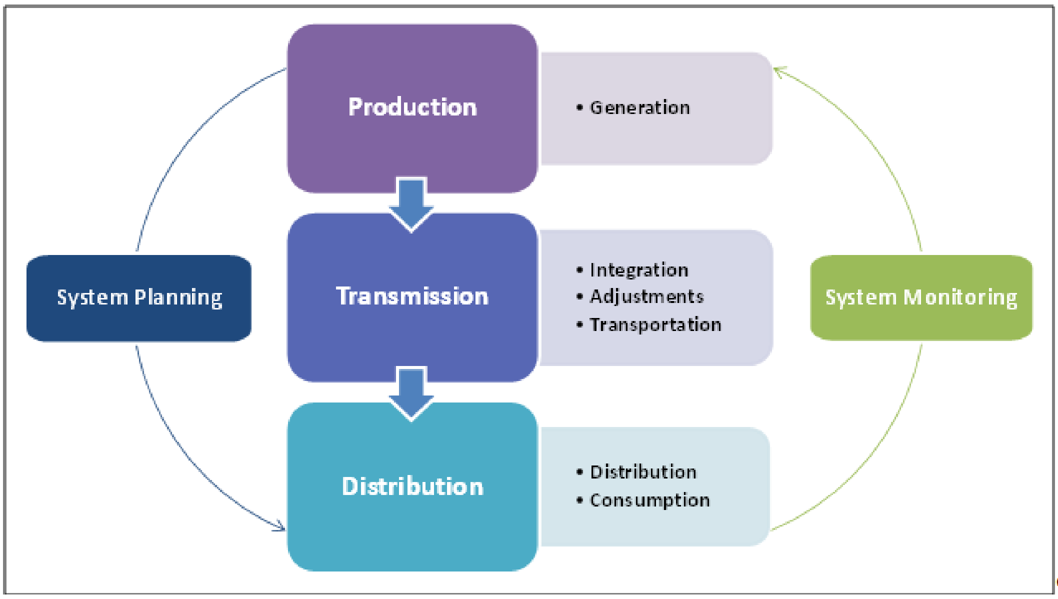
Specifically, energy-intensive industries are geographically concentrated in a few provinces such as Hebei, Shandong, Jiangsu, Liaoning, Shanxi, Henan, and Heilongjiang. Among these areas, Hebei is the largest industrial province surrounding Beijing and Tianjin (Li et al. 2016; National Development and Reform Commission 2017). Beijing, Tianjin, and Hebei are collectively known as Jingjinji, a name derived from the names of all three areas. Jingjinji region is not only the political center of the PRC but also one of the heavy industry bases. Specifically, Hebei represents 25% of national steel production and more than 5% of national cement production. Over the last decade, Jingjinji has been suffering from heavy smog, especially in the winter season, which is in large part attributed to fossil fuel consumption for the supply of district heating (Clean Air Asia 2015).

Tsinghua University (2018) suggests that the PRC may consider connecting neighboring cities' district energy systems to solve the shortage in clean heat sources and severe air pollution, primarily in Jingjinji. For example, large-diameter water tubes and networks could be established to link Beijing, Tianjin, Tangshan, and other cities. In this way, the main district heating facilities, including CHP plants, heat-only boilers, and industrial excess heat resources, could be integrated into an overall system. Thanks to smart heating technologies, heat-rich cities may thus provide surplus heat to heat-poor cities. This will help replace coal consumption and balance heat demand and supply across regional borders.

2.2 Characteristics of District Heating Systems

Industrial excess heat is usually heterogeneous, dispersed, and intermittent. These characteristics mean that to make industrial excess heat part of the baseload in a district heating system, the operator will need to maintain back-up heating capacities. Significant balancing costs are required to adjust and integrate various temperature grades of heat sources in district heating systems. It is therefore essential to having a complete understanding of the various costs associated with the utilization of industrial excess heat. In fact, this entails a rethink of our district energy system from both technological and investment perspectives (Liu, Park, and Zhong 2020).

Figure 1: Heat Market as a System with Key Components

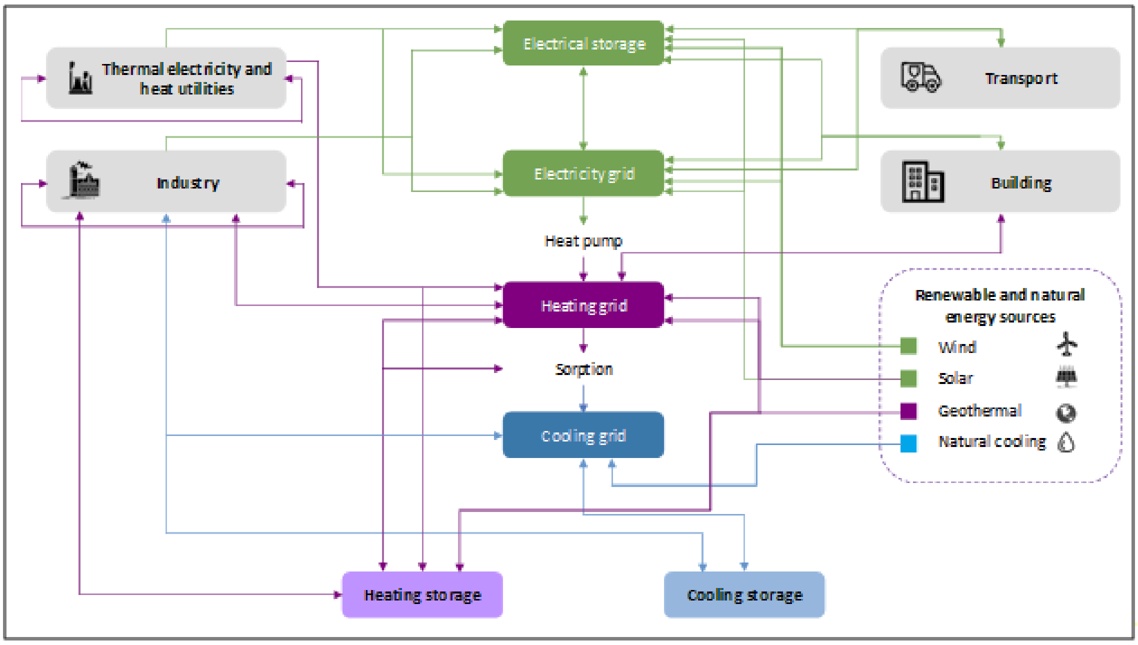


Source: Authors' own elaboration.

The value chain of district heating services involves a series of generating, integrating, adjusting, transporting, distributing, and consuming processes. Understanding the heat market as a system (Figure 1) from production to distribution and from the system planning to monitoring can facilitate the identification of energy efficiency opportunities. System-based screenings of technical and economic assessments usually lay the basis for the most cost-effective way to utilize excess heat in district energy systems. In many cases, these assessments also contribute to developing sound policies to support the long-term transformation of the whole energy system. For example, the European Union's Energy Efficiency Directive, endorsed in 2014, has made it compulsory to use industrial excess heat for district heating when the payback period for investments is less than four years.

From the technical point of view, in order to improve the energy efficiency of the district heating system, it is important to ensure that the return and supply temperatures are as low as possible while keeping the difference between the supply and return temperatures (the cooling) as large as possible (Söderholm and Wårell 2011). Changes in energy mix may have a large impact on district heating networks' operations. Various components of district heating networks are highly interdependent, both at a plant level and as a system. An important feature of the district heating is its operational inter-linkage between production, distribution, and consumption activities. For example, the level of the supply and return water temperatures can affect the heat and electricity output. Maintaining low temperatures can provide several benefits in a district heating system, such as increased electricity output from CHP plants, improved capacity of heat recovery from industrial excess heat, an increased coefficient of performance for heat pumps, and reduced distribution losses (Energy Technology Development and Demonstration Program 2014). Therefore, economic performance across the entire district heating system can vary greatly with the control of water temperatures.

Figure 2: Interconnections of Electricity and Thermal Energy in an Integrated Energy System



Source: Page 15, International Energy Agency (2014).

More importantly, utilization of excess heat from industrial sites in local district heating networks is one technology that can contribute to improving the flexibility of the whole energy system (Figure 2). In an energy environment of increased complexity, flexible technologies are highly valued: technologies that can rapidly adapt to operating loads, absorb or release energy when needed, or convert a specific final energy into another form of energy are increasingly important in energy systems (International Energy Agency 2016b).

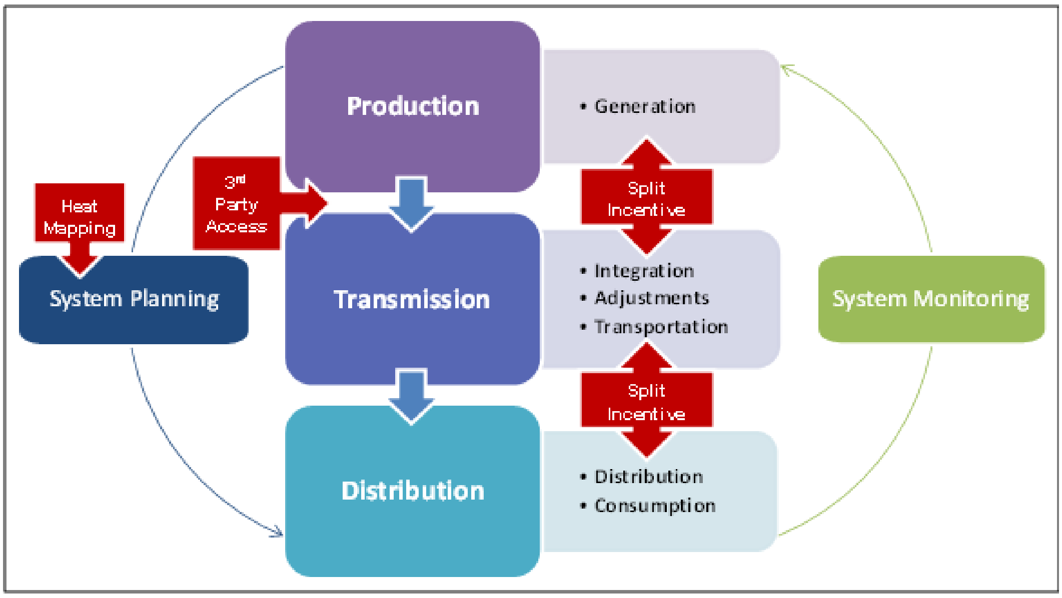
Increasing integration of fluctuating energy sources, such as renewables from solar and wind, requires enhancing the electricity grid's flexibility. The power system currently relies heavily on large-scale CHP plants in the northern PRC. The flexibility of the power dispatch system is constrained in the winter season since these CHP plants must be run to ensure heat supply as a social welfare. This leads to significant curtailment of wind-generated electricity. One option to provide this much needed flexibility is to use low-grade industrial excess heat to reduce reliance on CHP plants.

Nevertheless, mainstreaming heat planning into a broader energy policy framework is challenging. In the PRC, cities are responsible for developing their own heat policies, and the implementation of heat planning reforms depends in large part on local government agendas. Meanwhile, the electricity utilities are mainly owned by the central government and national champions. Therefore, integrating heat and electricity markets requires a holistic approach.

2.3 Challenges in the District Heating Market

In this section, we investigate three key challenges to investing in energy efficiency projects in district heating systems. These barriers include (1) split incentives between production, transmission, and distribution activities; (2) third-party access to the heat network; and (3) heat mapping in the energy system planning (Figure 3).

Figure 3: Key Barriers to Energy Efficiency for District Heating Systems



Source: Authors' own elaboration.

2.3.1 Split Incentives

Split incentives can occur across several business relationships, when entities capable of making improvements have split payoffs and risks, and the entity benefiting from the improvement has no ownership over the long-term savings. Indeed, multiple split incentives exist on both the supply and demand sides of district heating systems that prevent the scaling-up of energy efficiency investments (Hu et al. 2017; Liu, Yao, and Wei 2019).

Split Incentives between Heat End-users and Producers

The PRC's heat market has been reformed to some extent with consumption-based billing. However, commoditizing heat is not yet fully adopted by the market players and consumers. Heat billing is largely based on a flat energy cost per square meter regardless of the amount of energy consumed or level of comfort. Many employers pay employees' heating bills as part of the social welfare system (World Bank 2009). Heat tariffs are highly regulated to allow low-income consumers to access heating services, but result in heating companies claiming that the current level of heating revenue cannot sustain and improve heating services.

The Ministry of Housing and Urban-Rural Development (MOHURD) estimated that the consumption-based billing area was 805 million m^2 in 2013, representing about 7% of the total building stock. The World Bank launched an eight-year implementation program in 2003. However, the project fell short of its targets for promoting billing based on heat consumption across the country (World Bank and ESMAP 2012). This partially reflects the complexity of commoditizing heat in the country's social and economic contexts.

It is well known that lower system temperatures in district heating systems will lead to saving primary energy consumption (Söderholm and Wårell 2011). On the demand side, a range of measures must be put in place to enable end-users to adapt to low temperature operations. Some of these examples include implementing underfloor heating, fan-convector units, and radiators suitable for low-temperature systems. When the market is unable to send a price signal through heat prices, it is impossible to incentivize energy efficiency investments by heat end-users through energy savings.

Split Incentives between Heat Companies and Excess Heat Producers

District heating companies have an incentive to invest when they can capture the benefits of energy efficiency improvement. When a third party, such as an industrial plant, accesses the district heating network, this incentive may be split due to the separation of distribution and production functions. From the heat network operator's perspective, lowering the return water temperature implies an extra cost for network infrastructure adjustment. Meanwhile, this will improve the ability to capture excess heat from industrial plants through larger temperature difference, which will unexpectedly lead to higher remuneration for heat producers. When energy efficiency gains cannot pay for the infrastructure improvement investments, heat companies may lose the incentive to give heat network access to excess heat producers (International Energy Agency and Tsinghua University 2015). Financial return is often at the core of the split incentive. Lowering the return water temperatures implies increasing the profitability of excess heat producers while reducing that of heat companies. This results in a clear split incentive regarding the control of return water temperatures.

In order to address this split incentive issue, one solution is to set up a predefined return water temperature threshold in the heat supply agreement. Whenever the real return water temperature remains below this threshold, the threshold will be used to calculate the temperature difference to remunerate the heat producer. In such a way, the heating company's incentive to reduce the return water temperature will be not be undermined. Based on a preliminary analysis of pilot projects in the PRC, it is recommended to use the temperature of 44°C–45°C, which can result in a payback period of 3.5 years for both heat companies and excess heat producers (Tsinghua University 2018).

2.3.2 Third-party Access

Unbundling a vertically integrated utility company is considered a key measure in liberalizing the electricity market through increased competition. In particular, production is considered suitable for competition in a well-functioning electricity market. However, this is less common in the heat market because the municipality-owned heat utilities tend to prefer local heat producers and exclude third-party heat suppliers, partially due to geographical constraints.

Although the PRC government has a large stake in district heating systems and heavily regulates heat tariffs, the provision of heat services has been progressively commercialized, and the district heating market is now becoming open to the private sector. Similar to the deregulation of electricity and natural gas markets in many countries, the participation of the private sector challenges the natural monopolistic characteristics of municipal-owned heat companies with more competition (Wissner 2014).

The government may choose to regulate third party access in a non-discriminatory way. The actual costs of transmission and distribution will vary significantly depending on the characteristics of local sites. In addition, heat utilities may cross-subsidize transmission and distribution activities with inflated production costs. This information gap between the government and heat utilities will further complicate the harmonization of conditions and standards regarding third-party access.

2.3.3 Heat Resources Mapping

Heat planning is at the center of the interconnected energy system with multiple heat sources, as the central authority needs to guide the development of local markets and decisions in order to support regional and national ambitions. Acknowledging this interconnectedness also means implementing policies, incentives, and support to ensure adequate guidance on a local level to steer the implementation.

The heating system is undersized in big municipalities such as Beijing and Tianjin, while mostly larger than necessary to meet the current heat demand in medium and small sized cities. When the heating system operates at partial capacity, costs are greater, losses are higher, and service quality suffers. In such a context, there is a need for heat planning that accounts for available heat supply, current and projected heat demand, and system planning priorities.

Since excess heat is a by-product of industrial activities, any industrial policy to reduce or shut down energy-intensive industries will affect the availability of heat source supply and impose uncertainty on the long-term financial viability of investments. In such a context, heat planning can greatly help address the uncertainty.

Heat mapping in the PRC is currently mainly modeled with the consideration of only a few heating technologies. Improved heat mapping should include more detailed information on the heat demand profile, including building type, size, and weather data. Improved heat mapping can thus enable decision-making on clean energy solutions. A master plan can be formulated, including technical and economic analysis of the heat potentials from excess heat. Using the master plan as a reference, utilities, municipalities, and private actors can propose business cases to support the implementation of energy efficiency investments. If a common methodology is used, business cases can be compared and decided upon through an open tendering process, ensuring the development of the district heating system in the most cost-effective manner.

3. BUSINESS MODELS TO ENHANCE ENERGY EFFICIENCY OF DISTRICT HEATING

A business model includes a blend of ownership, financing, and revenue that provides value to customers. In this section, we suggest three business models: (1) a utility-led model with third-party access; (2) a heat production competition model; and (3) an Energy Service Company (ESCO)-integrated model. We provide case studies to highlight the extent to which each business model has enabled energy efficiency financing in district heating markets.

3.1 Utility-led Model with Third-party Access

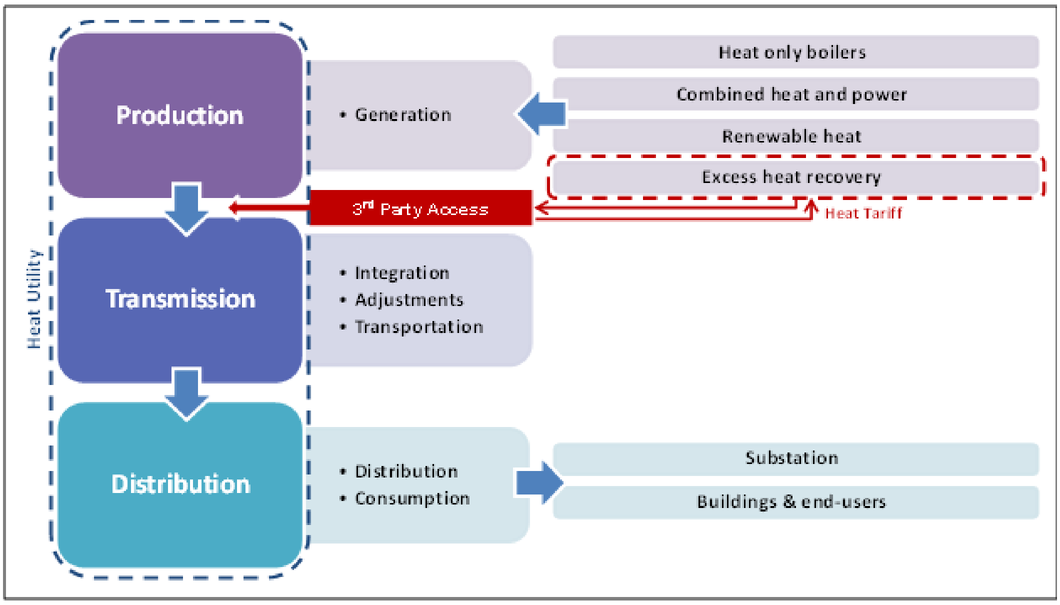
District heating is mostly characterized as a natural monopoly due to high fixed costs in the network infrastructure. A single supplier can supply the entire market at a lower cost than several smaller suppliers because of economies of scale. Heat utility companies traditionally adopt a vertically integrated structure to deliver production, transmission, and distribution activities. To some extent, a vertically integrated utility has the advantage of internalizing the energy efficiency benefits embedded within the system. However, it is noted that an integrated utility model has some trade-offs with local public debt capacity, lack of innovation, and monopoly behavior.

District heating requires long-term planning and financing, given the high fixed costs. In the PRC, the source of financing for new heating infrastructure traditionally comes from connection fees paid by real estate developers, the costs ultimately being passed on to heat end-users. To enable the integration of industrial excess heat in the heat networks, municipalities may need to invest in laying additional pipes and renovating existing networks. With a stake in the natural monopoly, municipalities can play a role in securing the heat market demand through regulations on the connection of existing and future buildings with a district heating system.

In addition, an integrated structure can facilitate a system approach for energy efficiency improvement since the utility will have more incentive to consider the heat system as a whole and not just one heat source. Due to the omnipresent split incentives in the district heating sector, this system approach can help ensure operational and economic efficiency in the long run, and pass on benefits of lower heating costs to customers if properly managed.

In a utility-led model with third-party access (Figure 4), a heat utility will need to negotiate an access agreement with excess heat producers. Since industrial excess heat provides a low marginal cost of heat supply, a monopolistic heat utility will be able to benefit from lowering its production cost in exchange for totally or partially financing investments associated with heat source connection, particularly additional network costs. When the excess heat increases the risk of existing heat capacities being replaced, the conditions of the third-party access must provide enough incentives for the market entry of new heat sources and incentivize utilities' capital expenditure on energy efficiency improvement (International Energy Agency 2016a).

Figure 4: Utility-led Business Model with Third-party Access



Source: Authors' own elaboration.

In this integrated business model, it is essential to provide third-party access to district heating networks in a non-discriminatory way. Otherwise, a vertically integrated heat monopolist often has financial incentives to discriminate against new heat producers and to favor its own heat generators. The government will need to encourage the application of integrated resource planning to look for the most cost-effective and efficient clean sources.

It is widely recognized that the monopoly market will need outright price regulation. Since the Chinese government provides subsidies to fossil fuels such as coal and natural gas, price signals cannot allow industrial excess heat to compete on an equal footing with other fossil fuels. Therefore, heat utilities may lose their economic incentive to allow networks access to the low-cost and clean heat sources.

Heat utilities can be required to meet an energy efficiency or emissions reduction obligation. This market design helps incentivize district heating utilities to negotiate with industrial facilities to deliver excess heat to the networks. Energy savings can be exchanged as a commodity through a market-based approach between utilities and other energy end-users. Existing experience of the European Union's Energy Efficiency Directive shows that the market is usually backed by legislation requiring utilities to increase annual energy savings through energy efficiency measures (Euroheat & Power 2012).

The excess heat to district heat project could be partially financed by a central government grant with a requirement for local municipalities to match the provided funds. The use of industrial excess heat in district heating systems often generates significant environmental benefits beyond the scope of the municipality administration. Central government intervention in terms of financial transfer across regions is necessary to internalize the benefits of air pollution reduction and emissions reduction.

The case of Qingdao city in the PRC provides an example. The municipality aims to replace a coal-dominant energy system with a clean and low-temperature district heating network. Instead of coal, Qingdao municipality wishes to use natural gas, solar, ground geothermal, and excess heat recovered from industrial plants to power its district heating systems.

The project is implemented by Qingdao Energy Group, wholly owned by the Qingdao municipality government. The local government has requested a loan of $130 million over a 25-year term, including a grace period of five years, from the Asian Development Bank. Qingdao Energy Group finances $133.6 million through equity contribution. The project has installed small-scale natural gas boilers, an excess heat recovery system from sewage plants and industries, heat pump systems, a solar heating system, a heat storage system, and low-temperature pipelines in eight locations across the city. The project is expected to benefit 420,000 people through improved air quality and savings on household heating bills (Asian Development Bank 2020).

To make use of industrial excess heat, Qingdao municipality imposes a zero-purchase price of industrial excess heat for the purpose of district heating services. Meanwhile, the municipality government implements energy efficiency standards in buildings and sets a cap on its district energy system's energy consumption. As shown in Table 1, providing district heating simply with natural gas, geothermal, and solar thermal technologies will lead to a net financial loss. With the support of zero-cost industrial excess heat, the overall project indicates a financial internal rate of return of 10% because of savings on fuel costs. In the absence of industrial excess heat, the project would not have been economically viable.

Table 1: Financial Internal Rate of Return with Various Fuels as Heat Sources in Qingdao Project

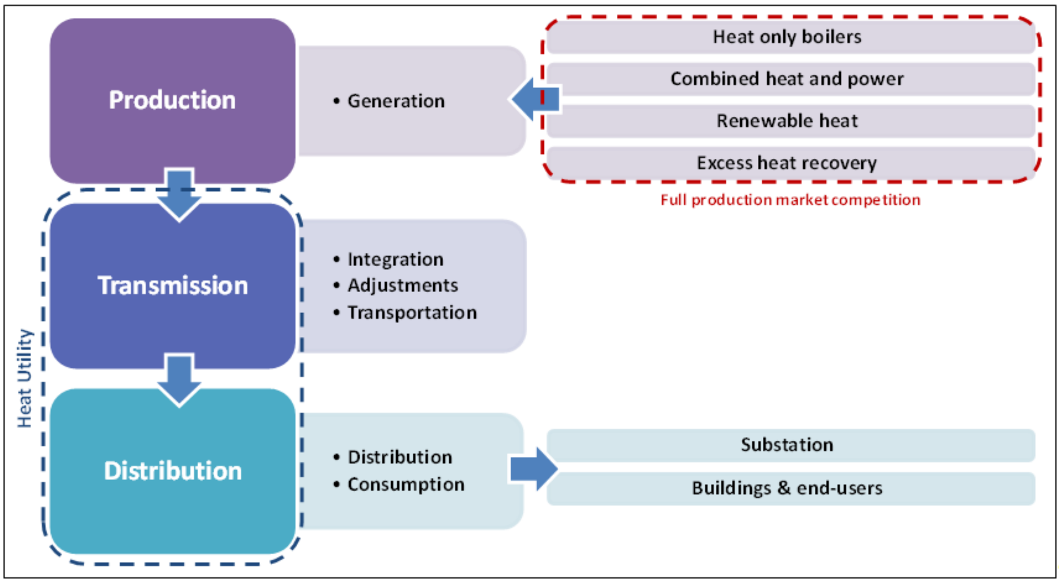
Heat Source	Financial Internal Rate of Return
1. Natural gas	–1.5%
2. Shallow ground geo-thermal	Negative
3. Solar thermal	Negative
4. Excess heat utilization	24%
Overall	10%

Source: Asian Development Bank (2020).

3.2 Heat Production Competition Model

Heat production can be unbundled from heat transmission and distribution to enable competition among multiple heat sources (Figure 5). If well managed, this competition can encourage energy efficiency improvement and cost-effective solutions for district heating systems. Two general forms of unbundling exist: ownership separation and accounting separation. While ownership separation effectively seeks to establish an independent network operator, the heat market must be advanced enough to play a primary role in pricing heat sources because the government's role will be limited to correcting any market failures through monitoring and prevention of power market abuse (World Bank and ESMAP 2012).

Figure 5: The Heat Production Competition Business Model



Source: Authors' own elaboration.

This level of maturity of the heat market is not often met in developing economies. Consequently, accounting separation provides an alternative, in particular when the ownership of heat transmission lines may be fragmented among several parties. The regulator can require heat utilities to unbundle the accounting of production, transmission, and distribution in order to increase the market transparency of network system costs. This functional separation can help reinforce the competitive nature of heat production. However, it may not completely remove heat utilities' incentive to impede third-party access to industrial excess heat. The regulator can determine ex-ante access provisions. If these preconditions are met by heat producers, the transmission operator is obliged to provide access to the network (Chittuma and Østergaarda 2014).

It is important to define the lowest cost supply requirements and ensure a transparent and non-discriminatory tendering process for the procurement of heat sources. A publicly-owned entity is in charge of procuring heat from private heat producers and selling heat to distributors to sell on to end-users. This so-called single-buyer model can help transition from a vertically integrated utility model to full market-based competition in the district heating market. Similar to the electricity market, this heat production competition model must establish licensing rules to encourage private investments in heat generation and prioritize the lowest-cost heat supply options.

The Nordic countries have largely adopted this model in their district heating markets. For example, the main characteristic of the heat market in Denmark is its non-profit policy. The municipalities own the transmission and distribution networks, but they buy heat from CHP, waste incineration plants, and industrial excess heat suppliers. The non-profit policy is expected to make heat utilities charge customers on a cost-covering basis and avoid market power abuse.

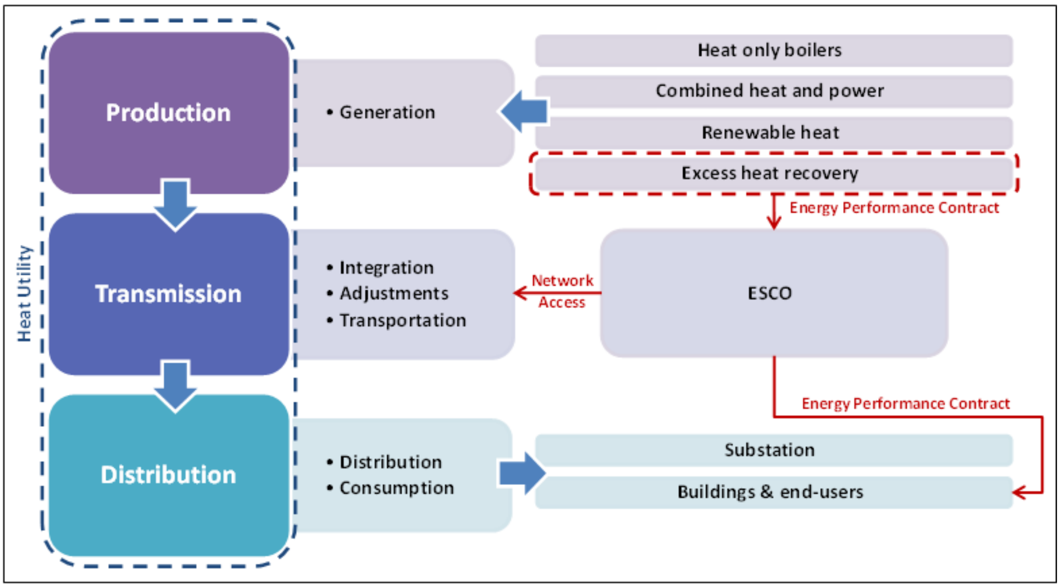
In the context of the PRC, significant investments for the extension and retrofit of heat pipelines may be required to exploit large-scale industrial excess heat. To fill the financing gap, public-private partnerships (PPP) are a useful tool to unlock private sector investments. A PPP typically allows a private entity to provide a public service for a period of time in exchange for a reasonable financial return. This involves a contract between a public sector authority and a private investor. The main purpose of the PPP is to allocate tasks and risks to the private sector best able to manage them (ESMAP 2008).

The experience of Anshan city in the PRC provides some meaningful insights. Anshan city has seen the heat market traditionally dominated by a few dispersed public and private district heating companies. District heating has relied heavily on inefficient coal boilers. On the other hand, the city hosts, Angang, one of the largest steel producers in the country. The city has decided to tap into 1GW potential of industrial excess heat produced by the Angang steel plant to heat 50 million m^2 of building floor area, representing 70% of the total heating area. To achieve this target, there is a need to develop a new transmission line to capture excess heat from the Angang steel plant and integrate it into the heat networks. Under a PPP framework, this transmission line has been invested in 60% by the government-owned Qianfeng district heating company and 40% by Fu An, a private company. The transmission line is expected to connect geothermal resources and two CHP plants with the heat networks in the future. Coal boilers are expected to be used only occasionally to meet peak load demand. In this case, the partnership between the municipality and the private sector has succeeded in unlocking investment in the transmission lines, which has enabled the utilization of industrial excess heat from the steel manufacturing process which would otherwise have been wasted (United Nations Environment Programme 2015).

3.3 ESCO-integrated Business Model

An ESCO can drive private investments in energy efficiency by linking heating companies and industries (Figure 6). This business model typically uses an energy performance contract (EPC) to implement an energy efficiency project. The cost saving derived from energy efficiency improvement is the source of the ESCO's revenue to repay the project investment. In this business structure, the ESCO needs to negotiate with industrial excess heat producers, the heat utility, and potential third-party financiers.

Figure 6: The ESCO-integrated Business Model



Source: Authors' own elaboration.

The private sector plays a leading role in enabling this business model. An ESCO can create an agreement with an excess heat provider through either a shared savings or guaranteed savings contract. Under a shared savings contract, the costs savings are split according to a predefined percentage, while under a guaranteed savings contract, the ESCO guarantees a certain level of energy savings. One important difference between the two models is that the performance guarantee is the level of energy saved, while shared savings are based on the cost of energy saved (International Energy Agency 2014).

Over the last years, ESCO investment in the PRC has increased by around 30% per year to reach 53 billion euros (371 billion yuan) and achieve annual energy savings of 124 million tons of standard coal equivalent. The number of ESCO firms has increased sixfold, from 782 in 2010 to 5,426 in 2015, creating cumulatively 607,000 jobs in 2015 compared to 175,000 in 2010 (International Energy Agency 2016b). However, the development of ESCOs in the district heating market is still at an initial stage, partially due to the market challenges outlined earlier.

It is worth noting that although an ESCO is usually wholly owned by the private sector, the government's role is still important in removing regulatory and policy barriers by addressing split incentives and facilitating access to finance (Retallack et al. 2018). Due to the supply uncertainty of excess heat as an industrial by-product, ESCOs face the challenge of mobilizing long-term financing from commercial sources. In many cases, ESCOs request the local government's guarantee to secure project financing.

Regarding the ESCO financing options, ESCOs assume all performance and technical risks under a guaranteed savings contract. For this reason, ESCOs rarely cover the investment repayment risk, and so the project is typically financed by industries through corporate or project finance. The investment payment schedule may be adjusted according to the level of savings: the higher the savings, the quicker the repayment. If the guaranteed savings are not achieved, the ESCO has to cover the debt service difference. In a newly established ESCO market, most actors may not have enough credit history to secure financing with their own balance sheets. In contrast, under the shared savings contract, which shifts partial performance risk to industry, an ESCO is more likely to provide third-party financing or co-invest with industry. It therefore assumes both the performance and the underlying customer credit risk (International Energy Agency 2014).

The PRC's heat market provides some interesting ESCO cases. For instance, Qianxi district is an area with a population of around 390,000 and located in the eastern part of Tangshan city. District heating has historically been fueled by coal-fired boilers. Growth in buildings' floor area has put upward pressure on the heat supply, while Qianxi has been facing restrictions on coal consumption due to the emissions reduction target.

A demonstration project was developed in Qianxi in 2014 to recycle excess heat from two new steel plants for the purpose of district heating. The project aims to reuse three categories of industrial excess heat—the cooling water of the blast furnace, the flushing water of blast furnace slag, and mixed steam from basic oxygen furnaces and rolling heating furnaces. It is estimated that the potential of this excess heat source can amount to around 217 MW, which is able to serve the heat baseload through to 2030.

The Qianxi Heran Energy Conservation Company created a joint venture with the local government. This newly established district heating company concluded a concession agreement with the local district heating agency; it also established a long-term contract with steel plants to purchase industrial excess heat. The ESCO then signed an EPC contract with the district heating network operator using the shared savings approach. The ESCO was in charge of providing third-party finance for project investments.

The project has planned three phases. The total investment for the first phase is approximately 283 million RMB, including excess heat transmission pipelines within the steel plants and beyond, heat recovery equipment, and a new heating station. The second and third phases are expected to cost an additional 51 million and 110 million RMB, respectively. Once completed, the project is expected to reduce annual district heating costs by around 63 million RMB by 2030. The overall project's payback period is estimated to be seven years (International Energy Agency 2016b).

4. PRICING INDUSTRIAL EXCESS HEAT

In the PRC, pricing industrial excess heat is not an easy task. Firstly, the presence of fossil fuel subsidies prevents the market from sending high energy price signals. Secondly, the close interlinking of economic performance among production, transmission, and distribution activities further complicates the pricing mechanism to translate the system benefits across district heating market players. In this section, we suggest four options for pricing industrial excess heat:

1. Estimating system costs
2. Free-cost excess heat
3. Establishing clean heat targets
4. Indexing against the next best alternative

4.1 Option 1: Estimating System Costs

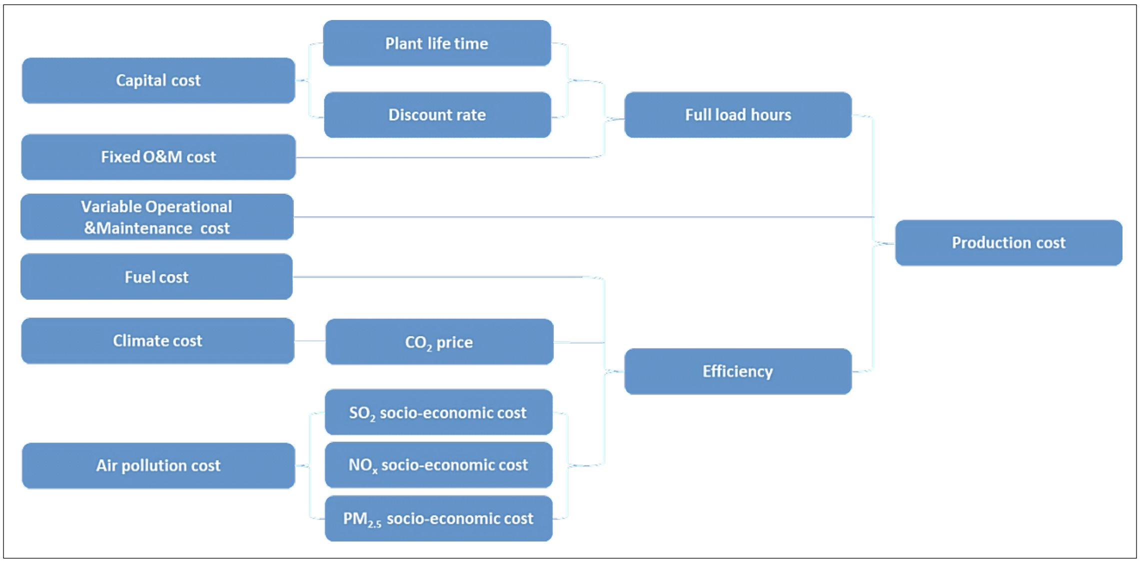
The first option is to regulate the price of excess heat with a systemic approach. This requires a holistic consideration of fixed and variable costs, back-up system costs, balancing costs, the potential impact on CHP plants, and the integration of renewable energy (Liu, Park, and Zhong 2020).

Specifically, the production costs reflect investment cost, fuel cost, operation and maintenance costs, and indirect costs such as environmental externalities due to air quality damage (SO_2, NO_X, and $PM_{2.5}$) and CO_2 emissions.

The network cost is typically related to transmission and distribution, which depend highly on distance and heat density, respectively. Similarly, temperature requirements, network layout, and size have a significant impact on the network cost.

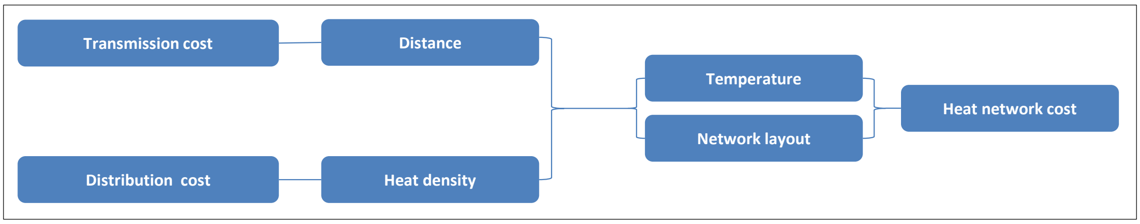
System integration costs include the cost of new heat and electricity infrastructure, the cost of integrating intermittent renewables into the energy system, and the cost of balancing unpredictable heat and power sources. System costs are collectively determined by the configuration of the heat and electricity systems, and the penetration level of excess heat.

Figure 7: The Heat Market Production Cost Structure



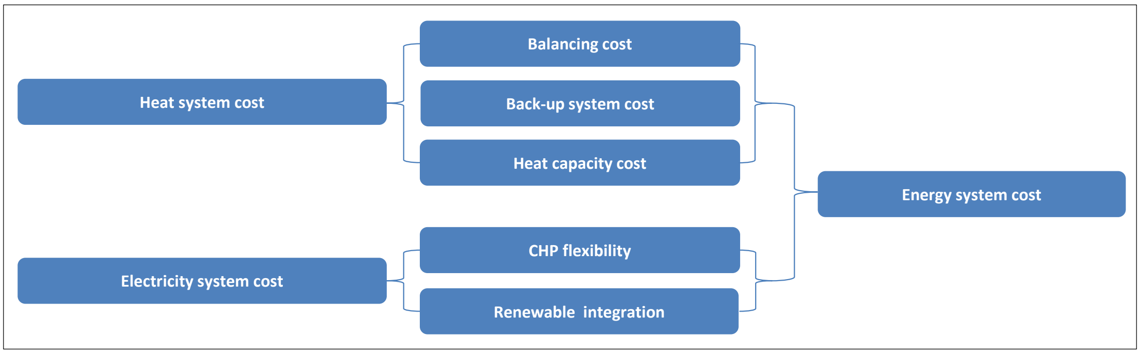
Source: Authors' own elaboration.

Figure 8: The Heat Market Network Cost Structure



Source: Authors' own elaboration.

Figure 9: The Heat Market System Integration Cost Structure



Source: Authors' own elaboration.

4.2 Option 2: Free-cost Excess Heat

When the government is not ready for, or not capable of, quantifying the costs and benefits from the system perspective, an intermediate approach entails implementing a free-cost policy, as the excess heat is viewed as a by-product of the industrial manufacturing process.

As illustrated in section 3.1, district heating utilities can make use of free-cost excess heat to integrate more options for clean heat sources. Given the high capital costs of heat networks, this free-cost policy can help strengthen the financial viability of the investments made by a natural monopolistic heat utility. Meanwhile, the government may consider establishing an energy efficiency obligation and/or a clean energy target. With a no-profit and social equity objective, this option can further allow the financial gains derived from the utilization of free-cost excess heat to be passed on to heat end-users.

4.3 Option 3: Establishing Clean Heat Targets

For the third option, the government can create a market-based instrument by setting an obligation on heating companies to diversify clean heat sources. This will incentivize heat companies to explore the most cost-effective clean heat sources. Similar to the EU Emissions Trading System or Green Certificates for renewable energy, clean heat targets enable a price signal of industrial excess heat to be sent to market players.

To date, over 23 cities in the PRC have committed to achieving the peak of their emissions earlier than the country-wide target. They have formed an Alliance of Peaking Pioneer Cities that together represent one-quarter of the PRC's urban carbon emissions. Improving the efficiency of the district energy systems is a major policy initiative to meet these cities climate change commitment.

4.4 Option 4: Indexing Against the Next Best Alternative

Excess heat is typically explored to replace a more expensive fuel that would otherwise have been used in district heating networks. The price of this alternative fuel can provide a good metric against which the excess heat price is benchmarked. The heat market must monitor heat production costs to establish the reference price for industrial excess heat.

While an alternative heat source in the counterfactual scenario may not be easily discovered, the regulator can also price industrial excess heat as a proportion of the least expensive heat production cost. To mitigate excessive fluctuation of excess heat prices, the regulator can set price caps below which the price setting will be more driven by the market and less reliant on regulatory oversight (Euroheat & Power 2012).

4.5 Impact of Industrial Excess Heat on District Heating Prices

Opening the heat market to excess heat producers will increase competition and incentivize more investments in energy efficiency. However, the extent to which the price of consumers' heating will change remains an open question. The size of the heat market and the number of competing firms are important in choosing an appropriate pricing policy (Söderholm and Wårell 2011).

In the PRC, the district heat sector is highly fragmented with many local heat suppliers. Consolidation of district heating within and across cities is expected to bring about benefits of economy of scale and optimize the dispatch of clean heat sources. Indeed, the entry of new market players can increase the market competition. Nevertheless, when the competition is limited by the presence of a few dominant market players, heating utilities may have a strong incentive to inflate the system costs of introducing industrial excess heat in order to cross-subsidize their own production and distribution activities (Söderholm and Wårell 2011).

Most cities in the PRC apply a fair rate of return policy with two pricing components: a regulated network price and a market price for the delivered heat (Söderholm and Wårell 2011). This two-part pricing structure has the advantage of reconciling production efficiency and financing incentives.

On the one hand, the increasing penetration of industrial excess heat in the district heating network can lower the marginal cost of heat supply. These savings in operational costs are expected to put downward pressure on heat prices. On the other hand, introducing industrial excess heat may imply additional costs of retrofitting and balancing heat networks. The net heat prices may still increase as a result of capital-intensive infrastructure investments.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

Examining the heat market as a system enables the identification of system opportunities and challenges for investments in energy efficiency. We identify three business models to enable increased financing for low-grade excess heat utilization. Getting the heat tariff right is essential for translating the system benefits into market value. The following policy implications arise from our analysis.

Firstly, the government authority should make low-grade excess heat visible in energy statistics. For this, there is a need to develop a guideline to help local authorities assess and report the potential for district heating and any additional costs of using excess heat. Heat resource mapping is expected to identify industrial clusters and assess heat supply and demand across regions. This will allow the assessment of transmission distances between excess heat producers and district heating networks.

Secondly, the PRC should enhance utilization of low-grade excess heat as a structural energy efficiency measure. The national energy authority can develop a guideline on cost-benefit analysis of a range of clean heat solutions. The country must consider multiple options for integrating heat and power sectors so that the system costs and benefits can be better understood. This will support the market with a scientifically sound analysis to promote improvement in the energy efficiency of district heating.

Thirdly, the government needs to improve third-party access to district heating networks. The key measures include promoting transparency of heat network pricing, reinforcing the competition of heat production, and improving PPP concession bidding. It is also important to establish least-cost heat procurements and enhance investors' appetite for clean heat options.

Last but not least, the government will need to review current public support measures for investments in energy-efficient district heating. Given the inherent uncertainty arising from industrial excess heat and complex institutional arrangements, the government may provide guarantee funds or risk-sharing facilities, thus enabling the private sector to access commercial loans. The policy package also includes harmonization of the pricing policies related to air pollutants, carbon emissions, and fossil fuel subsidies.

Although our study focuses specifically on the PRC, the policy and financing issues present global opportunities to improve energy efficiency in district energy systems. For future research, market mechanisms to integrate heat and power sectors for improved energy efficiency merit further investigation.

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